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P.A. Crowther

Hierarchical Structure of HII Regions - Ultracompact, Compact, and Extended Components

Kee-Tae Kim and Bon-Chul Koo

Astronomy Program, SEES, Seoul National University, Korea

Abstract. We have observed extended emission physically associated with 15 out of 16 UC HII regions with large ratios of single-dish to VLA fluxes. We discuss their implications for the age problem of UC HII regions and the evolution of HII regions.

Recently extended emission was observed around a few tens UC HII regions (Koo et al. 1996; Kurtz et al. 1999), suggesting that the ultracompactness of UC HII regions may arise from the missing short baseline of interferometric observations. However, the relationship between UC HII regions and the surrounding extended emission is poorly understood at present.

In order to address this issue, we carried out radio continuum and radio recombination line (RRL) observations of 16 UC HII regions, which were selected from the catalog of Wood & Churchwell (1989) because of their simple morphology and large (>10) ratios of single-dish to VLA fluxes. The radio continuum observations were made with $\sim 30''$ resolution at 21 cm using the VLA DnC-array. The H76α RRL observations were undertaken using the Green Bank 43 m telescope (FWHM$\simeq 2'$). We also mapped molecular clouds associated with the 16 UC HII regions in the ^{13}CO J=1$-$0 and CS J=2$-$1 lines with the NRAO 12 m (FWHM=$60''$) and the TRAO 14 m (FWHM=$60''$) telescopes, respectively.

We detected extended emission towards all our sources. The extended emission consists of one to several compact ($\sim 1'$ or 0.5$-$5 pc) components and a diffuse extended envelope (Fig. 1*a*). All the UC HII regions but two are located at the peaks of the compact components. We derived the ratios of single-dish to VLA fluxes for 52 UC HII regions with simple morphology in the catalogs of Wood & Churchwell (1989) and Kurtz et al. (1994), and found that most of them have large ratios. Therefore, most UC HII regions are likely to be associated with extended emission as our sources (see Kim & Koo 2001a for details).

We have found no significant velocity difference among the UC HII region, compact component(s), and extended envelope in all the sources except one. This indicates that the three components are physically associated. The UC HII regions correspond to the peaks of their associated compact components, as noted above, and the compact components with UC HII regions are more compact than those without UC HII regions. If the two are ionized by separate sources, one would not expect these correlations. Hence, the UC HII region and its associated compact component in each source are likely to be excited by the same ionizing source.

Recent high-resolution molecular line studies of massive star-forming regions have revealed 'molecular clumps' and 'hot cores' therein (e.g., Cesaroni et al. 1994). The hot cores are believed to be the sites of massive star formation.

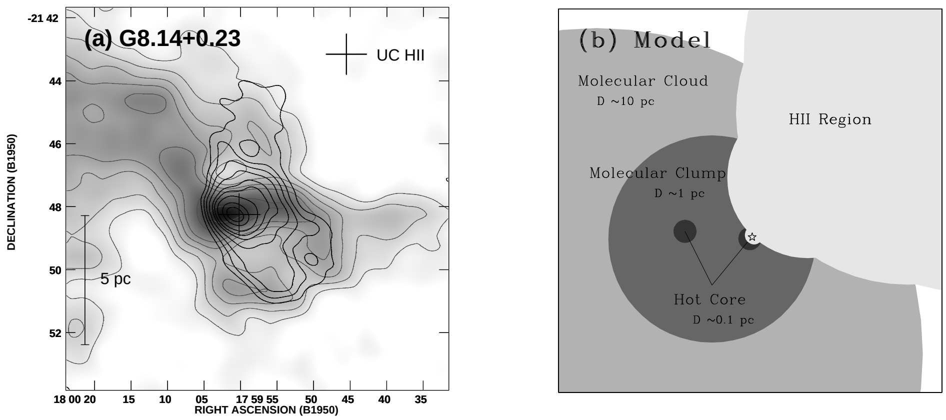

Figure 1. (a) Radio continuum (contours) and ^{13}CO line images for G8.14+0.23; (b) Schematic model (see text)

The sizes of the hot cores and molecular clumps agree roughly with those of UC HII regions and their associated compact components, respectively. Based on these observations, we propose a simple model in which the existence of the extended emission around UC HII regions can be explained by combining the Champagne flow model with the hierarchical structure of massive star-forming regions (Fig. 1*b*). Our molecular line observations show that ^{13}CO cores are associated with the compact components regardless of the presence of UC HII regions, while CS cores are preferentially associated with the compact components with UC HII regions. This strongly suggests that the compact components with UC HII regions are in an earlier evolutionary phase than those without UC HII regions. By comparing molecular line data with radio continuum and RRL data, we found champagne flows in 10 sources in our sample (Fig. 1*a*). These observations are consistent with our model (see Kim & Koo 2002 for details).

In conclusion, most sources known as UC HII regions may not be "real" UC HII regions but ultracompact cores of more extended HII regions. Therefore, the "age problem" of UC HII regions does not seem to be as serious as earlier studies argued. The ultracompact, compact, and extended components of HII regions may not represent an evolutionary sequence and could coexist for a long ($>10^5$ yr) time. Such a structure of HII regions is likely to be closely related to the hierarchical structure of parental molecular clouds.

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